

General Service LED Lamps

Performance gains and dropping prices have made LED products increasingly viable for general illumination. How do they stack up against the familiar incandescent light bulb?

Incandescent lamps were introduced more than a century ago, and they remain in widespread use today. In fact, the installed base of incandescent A lamps (Figure 1) is currently greater than that of any other lamp type. Incandescent lamps are particularly popular in residential applications due to familiarity with the technology, the low initial cost and ease of replacement, and the quality of light emitted. However, there is tremendous potential for energy savings by replacing incandescent lamps with more efficient halogen, CFL, or LED alternatives. For example, if the entire nationwide installed base of incandescent A lamps was converted instantaneously to LED, an estimated 84.1 TWh per year would be saved—equating to the total annual electricity consumption of nearly seven million residential households.¹

This fact sheet addresses direct replacements for general service incandescent lamps—including most A lamps and some other formats—as defined in the Energy Independence and Security Act of 2007 (EISA 2007).² Products affected by this legislation include standard incandescent or halogen lamps that are intended for general service applications, have a medium screw base, emit between 310 and 2,600 lumens, and are capable of being operated at a voltage range at least partially within 110 and 130 V. Products in this category emit light in all directions (i.e., are omnidirectional), are generally more functional than decorative

¹ From the DOE report, "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications" (January 2011), provided at www.ssl.energy.gov/tech_reports.html.

² An overview of EISA 2007, including a discussion of excluded lamp types, is provided at www.energysavers.gov/lighting.



Figure 1. A lamps (left) are the most common type of general service incandescent lamp, but others (such as some G- or BT-shaped lamps) are also included in the definition.



The winner of the L Prize 60 W replacement competition features remote phosphors that appear yellow when in the off state. (www.lightingprize.org)

in application, and are fully integrated (i.e., all components are integral to the lamp). With some basic guidance, prospective buyers can find cost-effective alternatives which save energy without compromising the quality or quantity of illumination.

Lower Wattage, Equal Lumens

When evaluating energy-saving alternatives to conventional lamps, emphasis should be placed on lumen output rather than input power (watts). This is because luminous efficacy—the quotient of lumen output and input power—can differ greatly between product types. For example, the integrated LED lamp that won the L Prize competition (www.lightingprize.org) produces as many lumens as a 60 W incandescent A lamp while drawing just 10 W of power. By comparison, equivalent CFLs typically draw 13 to 15 W.

EISA 2007 established new performance requirements for general service incandescent lamps. The affected incandescent and halogen lamps were classified based on lumen output, with input power restricted for each output class—this resulted in minimum efficacy criteria as shown in Table 1. Traditional incandescent A lamps do not satisfy these requirements, but some newer halogen lamps comply. Integrated LED lamps and CFLs are excluded from the legislation but most feature efficacies well above these values.

Table 1. EISA 2007 requirements for general service incandescent lamps.

Rated Output (lm)	Maximum Input Power (W)	Minimum Efficacy (lm/W)	Inc. A Lamp Affected (W)	Effective Date
1490–2600	72	20.7	100	Jan. 2012
1050–1489	53	19.8	75	Jan. 2013
750–1049	43	17.4	60	Jan. 2014
310–749	29	10.7	40	Jan. 2014

A Wide Range of Performance

Many currently available integrated LED lamps meet or exceed the performance of general service incandescent lamps, but performance varies widely and is not always accurately portrayed by manufacturers. Several market-based programs have been established by the U.S. Department of Energy (DOE) to help prospective buyers make informed decisions. One such program, LED Lighting Facts, publishes performance data from manufacturer-supplied LM-79 test reports,³ and allows partner manufacturers to use the voluntary LED Lighting Facts label on products.⁴ This information facilitates accurate comparison of products. Another DOE program, CALiPER, goes one step further by anonymously acquiring and testing LED and benchmark

products, thereby helping to ensure rated performance accurately characterizes products available on store shelves and through other distribution channels.⁵

Figure 2 summarizes lumen output and efficacy data from LED Lighting Facts and CALiPER. Efficacies of LED products vary substantially but are consistently higher than the incandescent and halogen benchmarks, and in some cases surpass typical CFLs. In recent years, there have been notable improvements in both efficacy and lumen output of LED products. For example, CALiPER testing showed that the average efficacy of LED A lamps acquired from retail stores in 2010 and 2011 improved from 40 to 58 lm/W during that period. A majority of the products tested by CALiPER or listed by LED Lighting Facts already exceed the 2020 backstop requirement of 45 lm/W established by EISA 2007. Many also meet the more stringent ENERGY STAR® (Integral LED Lamps version 1.4) efficacy requirement of 50 lm/W (< 10 W) or 55 lm/W (≥ 10 W).

Beyond Lumens and Watts

Although early CFLs could emit equal lumen output while drawing less power than incandescent lamps, many left consumers dissatisfied with the quality of light. This underscores the need to consider more than just lumens and watts when comparing

³ See the DOE fact sheet, "Understanding LM-79 Reports" (www.ssl.energy.gov/factsheets.html).

⁴ For more information on LED Lighting Facts, please visit www.lightingfacts.com. Note that a separate Lighting Facts program has been developed by the Federal Trade Commission (FTC), which mandates labels on medium screw-base lamps.

⁵ The CALiPER and LED Lighting Facts programs require that testing laboratories be independent and have LM-79 accreditation which includes proficiency testing, such as that available through the National Voluntary Laboratory Accreditation Program (NVLAP). For details, please visit www.ssl.energy.gov/test_labs.html.

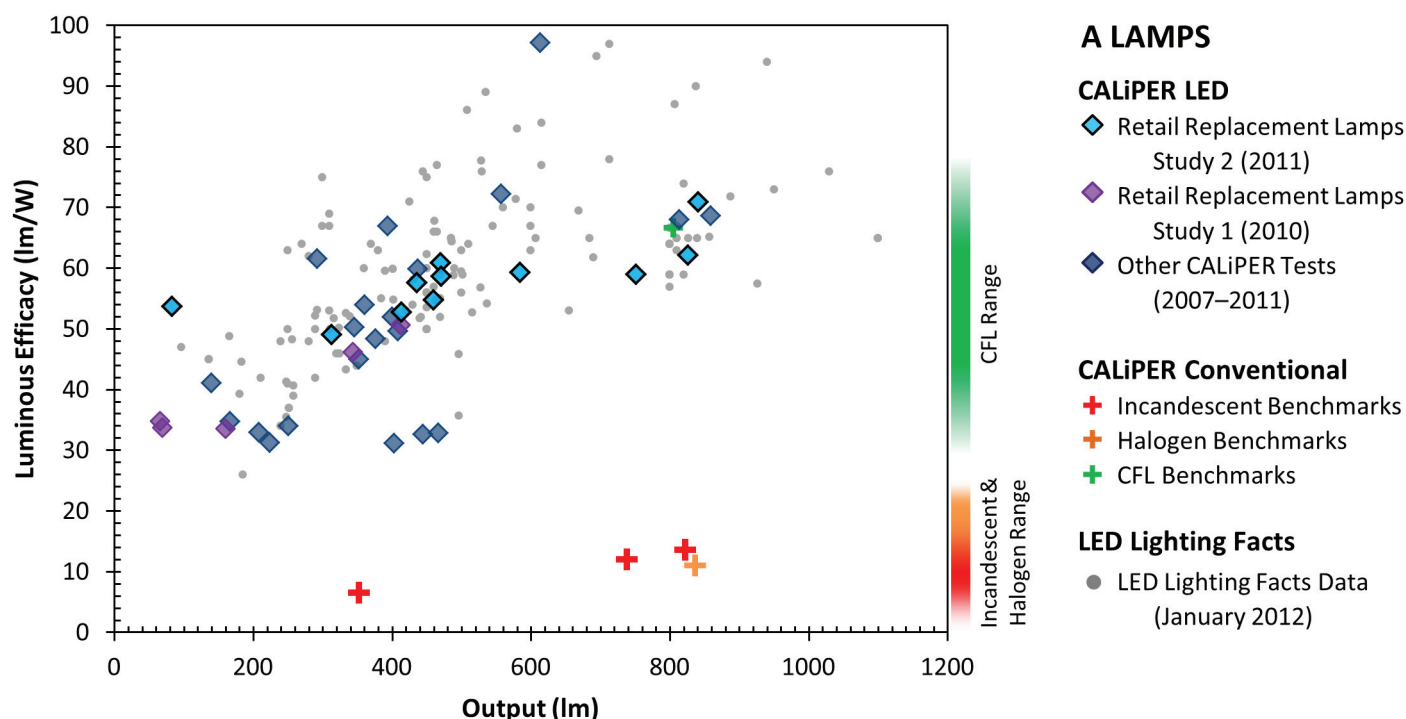


Figure 2. Luminous efficacy (lm/W) versus output (lm) for LED A lamps compared to conventional benchmarks. Generally, the efficacy of LED A lamps is equal to or better than typical CFL A lamps. Some lamps have lumen output equivalent to a 60 W incandescent lamp, and a few are beginning to reach higher equivalency levels.

products.⁶ Among others, key equivalency criteria to consider include color attributes, spatial distribution of light, electrical and mechanical compatibility, rated lifetime, warranty, and cost. In some situations differing performance may be welcomed as an improvement, but it is generally safer to assume that an integrated LED lamp must be equivalent to the product it replaces.

Color Attributes

Two basic metrics of color quality are correlated color temperature (CCT) and the color rendering index (CRI).⁷ A nominal CCT of 2700 to 3000 K is generally appropriate if the intent is to match the appearance of an incandescent lamp. The highest nominal CCT allowed by ENERGY STAR for integrated LED lamps is 4000 K, although higher CCTs may be preferred by some users.

ENERGY STAR also requires a minimum CRI of 80 to ensure that the apparent color of objects will not differ greatly whether illuminated by the LED product or by a standard reference source. This criterion is met by many LED products, but not all. Consumers should be diligent in reviewing manufacturer-listed values to ensure expectations are met.

Spatial Distribution of Light

Omnidirectional lamps are generally most effective when installed in pendants and other luminaires designed to emit light in all directions (see Figure 3). By contrast, a directional lamp (e.g., PAR or R) would be better suited for use in recessed downlights since a smaller proportion of the output would be trapped in the luminaire. Some LED products are designed to resemble incandescent A lamps in physical appearance—and are indeed marketed as suitable replacements—but actually behave more like directional lamps. Polar plots of luminous intensity offer one method of identifying such products. For example, it is clear from Figure 4 that CALiPER 10-55 more closely replicated the omnidirectional distribution of the benchmark incandescent A lamp than did CALiPER 11-03.

For omnidirectional lamps to achieve ENERGY STAR qualification, the luminous intensity at any angle up to 135° from the

center-beam axis cannot differ by more than 20% from the mean intensity for this region, and at least 5% of the total lumen output must be emitted in the 135°–180° region. These criteria were both satisfied by CALiPER 10-55, but neither was met by CALiPER 11-03.

Electrical and Mechanical Compatibility

Beyond performance equivalency, basic electrical and mechanical compatibility are important to consider when choosing a lamp, especially if an integrated LED lamp is replacing a conventional lamp:

- If the physical profile of the LED product differs substantially from the lamp for which the luminaire was designed, performance may be compromised due to optical misalignment or blocked light. In the worst case, the replacement lamp may not fit at all. Such problems may be revealed by side-by-side visual comparisons and trial installations.
- The lamp must feature a base that matches the socket into which it will be installed. By definition, general service incandescent lamps have an E26 (medium) screw base, but some alternatives have other base types (e.g., GU-24).⁸
- Many integrated LED lamps are labeled as dimmable, but actual dimming performance might vary depending on the combination of devices being used. If the lamp will be controlled by a dimmer, then it should be rated to be compatible

⁸ For example, California Title 24 established statewide criteria for GU-24 bases and sockets (www.energy.ca.gov/title24).

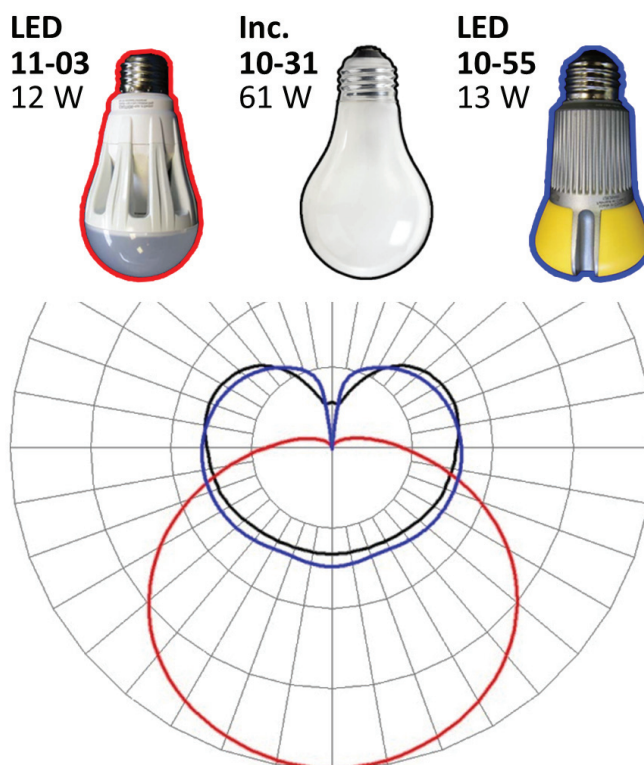


Figure 4. Polar plots of luminous intensity distribution for three different A lamps tested by CALiPER. CALiPER 10-55 more accurately replicated the distribution of a 60 W incandescent lamp than did CALiPER 11-03.

⁶ See the DOE fact sheet, “Establishing LED Equivalency” (www.ssl.energy.gov/factsheets.html).

⁷ See the DOE fact sheet, “LED Color Characteristics” (www.ssl.energy.gov/factsheets.html).

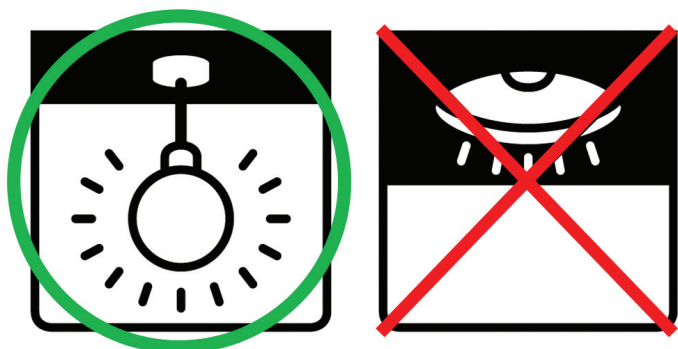


Figure 3. Omnidirectional lamps tend to be more compatible with pendant-type luminaires or table lamps than with recessed downlights. (Image credit: ENERGY STAR)

with the specific type of dimmer used.⁹ This can increase the likelihood—but does not guarantee—that the LED product will dim appropriately.

- Integrated LED lamps sold in the United States must bear a mark (i.e., label) from a Nationally Recognized Testing Laboratory (NRTL) indicating compliance with safety regulations.¹⁰

Rated Lifetime and Warranty

Expected lifetime can vary widely among different lamp types. ENERGY STAR qualified LED lamps are rated to remain in service for at least 25,000 hours—approximately 23 years when operated for an average of three hours per day—which is significantly longer than typical incandescent lamps (1,000 hours) or integrated CFLs (6,000–10,000 hours). ENERGY STAR qualified products must also feature a warranty, covering repair or replacement, of at least three years from the date of purchase. Some LED manufacturers claim much greater lifetimes, which often cannot be substantiated using available industry standards. Although some of these claims may prove valid, they are generally best regarded with skepticism, particularly if the warranty is not of commensurate duration or if the product is not carried by a reputable retailer.

Cost and Return on Investment

LED product price is not always a clear indicator of performance, but relatively low prices are often associated with some form of compromise. In comparing lamps that produce an equivalent quantity and quality of illumination, current prices for LED products are substantially higher than for more established technologies. Table 2 provides an example of a life-cycle cost analysis, which accounts for rated life, energy costs, and the time value of money. Although energy rebates were excluded from this analysis, such incentives can offset the purchase price of energy-efficient products such as integrated LED lamps and CFLs.

The cost analysis presented in Table 2 is a generalized example—actual pricing may vary from store to store or between regions. Prices are also changing rapidly; for example, the average price per lumen of LED lamps acquired by CALiPER from retail stores decreased by 55% between August 2010 and November 2011.¹¹ Some integrated LED A lamps already represent a cost-effective alternative to incandescent and halogen lamps, and if the current trend continues they will soon offer cost savings compared to integrated CFLs.

Table 2. Life-cycle costs and savings (2012 dollars) for four different lamps. The example CFL is slightly more cost-effective than the example LED, although there is considerable variability among products.

Technology	Inc.	Hal.	CFL	LED
Rated Input Power (W)	60	43	14	12
Rated Output (lm)	860	750	800	800
Rated Lifetime (hours)	1,000	1,000	8,000	25,000
Lamps Required	25	25	4	1
Initial Unit Cost (\$)	0.37	1.50	4.50	25.00
Present Value of Replacement Unit Costs (\$)	6	23	6	-1
Present Value of Energy Costs (\$)	103	74	24	21
Total Life-Cycle Cost (\$)	109	98	34	45
Net Savings (\$)	n/a	11	74	64

Note: These calculations assume three hours of operation per day and an initial electricity rate of \$0.11 per kilowatt-hour (kWh)—both of these values are the same as used for the FTC Lighting Facts label. The calculations also assume a 4.0% real discount rate (constant-dollar analysis) and end-of-year discounting, utilize NIST forecasts of future U.S. residential sector electricity rates, account for residual value, and exclude labor costs. The results are based on a 22-year analysis period.

Conclusions

Although performance varies widely among available general service LED lamps, the technology continues to improve even as the price per lumen decreases. Some LED products have already demonstrated equivalence to the ubiquitous 60 W incandescent light bulb, and higher-output alternatives to 75 W and 100 W incandescent A lamps will be tested by CALiPER and LED Lighting Facts in the near future. When chosen carefully, LED products can offer substantial energy savings without compromise to the quantity or quality of illumination, while also saving money in the long run.

⁹ See the DOE fact sheet, “Dimming LEDs,” for details (www.ssl.energy.gov/factsheets.html).

¹⁰ Integrated lamps must satisfy UL 1993 and UL 8750. For a list of NRTLs, visit www.osha.gov/dts/otpc/nrtl.

¹¹ Additional information can be found in the CALiPER exploratory study, “Retail Replacement Lamps – 2011.”

